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NEW MATERIALS FOR AIRCRAFT TURBOMACHINERY

M. El Gammal

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NEW MATERIALS FOR AIRCRAFT TURBOMACHINERY

Maurice El Gammal*

1. Introduction

The rapid development of aircraft turbines, which has transformed aviation during the last three decades, has resulted in part from improved materials performance. /25**

In the very keen competition among engine manufacturers, future advances in materials performance and endurance — key components of overall profitability — will play determining roles.

Innovation in this materials area must be looked at from two points of view: the new materials being developed give hope of substantial improvements in which one cannot be disinterested, but at the same time, the expense and time required for engine testing are such that even very large companies cannot allow themselves to accumulate failures. Research on new materials, deeper understanding of actual operational conditions, critical evaluation of possible applications by means of appropriate testing, development of effective inspection methods, and, of course, development of the most economical fabrication methods possible, are thus equally necessary activities, and are inseparable.

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At present, the materials used for turbine construction are mainly titanium alloys, classic alloy steels, high-temperature stainless steels, and nickel-base or cobalt-base heat-resistant alloys.

While the classic alloy steels are used mainly in mechanical components — shafts, gears — the compressors are fabricated, for the most part, from either martensitic stainless steels or from titanium alloys. Although their cost is relatively high, the latter are tending to replace the steels, whose mechanical properties are still satisfactory — this reflects the importance placed on reducing the weight of aircraft engines. The hottest compressor stages now require use of nickel-base alloys, until only recently reserved for the turbine stages. These stages are now fabricated from very highly developed nickel-base alloys, or from cobalt-base alloys in the case of certain stator blades. The combustion chambers and the afterburner nozzles use sheet alloys which range from simple austenitic stainless steels to nickel- or cobalt-base heat-resistant alloys. Aluminum alloys, formerly used in compressors, are tending to disappear because they cannot withstand the violent impacts which arise for example, when the engine ingests birds.

2. Development of Standard Alloys

2.1. Titanium Alloys

Studies in this area are directed toward improving low-cycle fatigue life, i.e., fatigue related to cyclic loading during takeoff, flight, and engine shutoff, which determine mainly compressor life, and toward development of alloys usable at the highest possible temperatures, in order to limit use of nickel-base alloys (which have twice the density) in the high-pressure compressor stages. Among the most-used alloys at present, in addition to the well known T-A6V there are T-A8DV and T-A6ZrD (IMI685) which contain 8% aluminum, 1% molybdenum and 1% vanadium and, on the other hand, 6% aluminum, 5% zirconium, 0.5% molybdenum and 0.2% silicon. TMCA [Titanium Metals Corporation of America] has recently announced a new alloy containing 6% Al, 2% Sn, 1.5% Mo, 0.3% Bi, and 0.1% Si, with higher creep-resistance /26 than previous alloys, and which can be used to 550 or 600° C. The chief concern of engine manufacturers seems to be better mastery of the fabrication of present alloys, however, in order to improve reliability.

2.2. Nickel-Base Alloys

Cast alloys have slowly replaced wrought alloys for turbine blades. In this way a considerable improvement has been obtained in creep resistance, together with an appreciable reduction in blade cost. Directional solidification, developed a few years ago in the United States by Pratt & Whitney, allows one to obtain grain boundaries parallel to the centrifugal force, and thus little affected by it (Figure 1). Creep resistance is thus improved and there is a large increase in ductility, leading to better resistance to thermal fatigue. It is possible to go even further by making blades with no grain boundaries — they are called single-crystal although it would be more exact to call them single-grain — which improves the creep resistance a little more, and should allow design of special-purpose alloys which would not require the addition of the alloying elements which strengthen the grain boundaries of alloys with normal structures. Application of directional-solidification techniques is slowed by the high cost; nevertheless, directional-grain

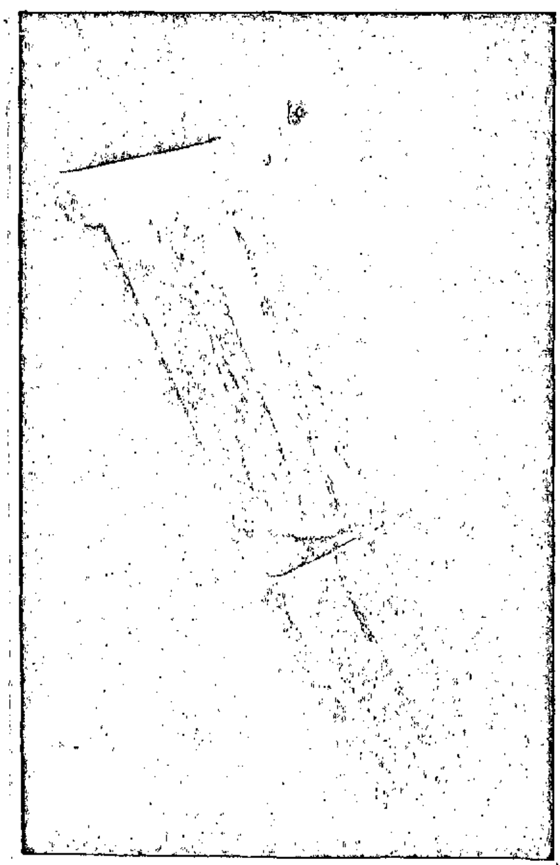

Figure 1. Rough casting of nickel-alloy turbine blade obtained by directional solidification

blades have already been used in some engines.

Turbine-disc alloys must resist creep, and especially low-cycle fatigue. Powder metallurgy has made important progress in this area: by disrupting liquid metal by an argon jet, one obtains spherules a few tenths of a millimeter in diameter; these can be compacted by extrusion or by hot isostatic pressing, then forged or rolled. From alloys which are commonly used in the cast condition, such as IN 100 one can thus obtain very-fine grained alloys (Figure 2). Each of the spherules consists of a large number of grains, which consequently do not coarsen much. These alloys do not have segregation, and possess very different mechanical properties from the same alloy in the cast condition: the high-temperature tensile strength is low because /27
of the small grain size. This makes forging relatively easy, but prevents use of the material for rotor blades in the high-pressure turbine stages. On the other hand, these alloys have exceptionally high elastic limits and low-cycle fatigue strengths at the temperatures at which turbine disks operate, generally below 750° C.

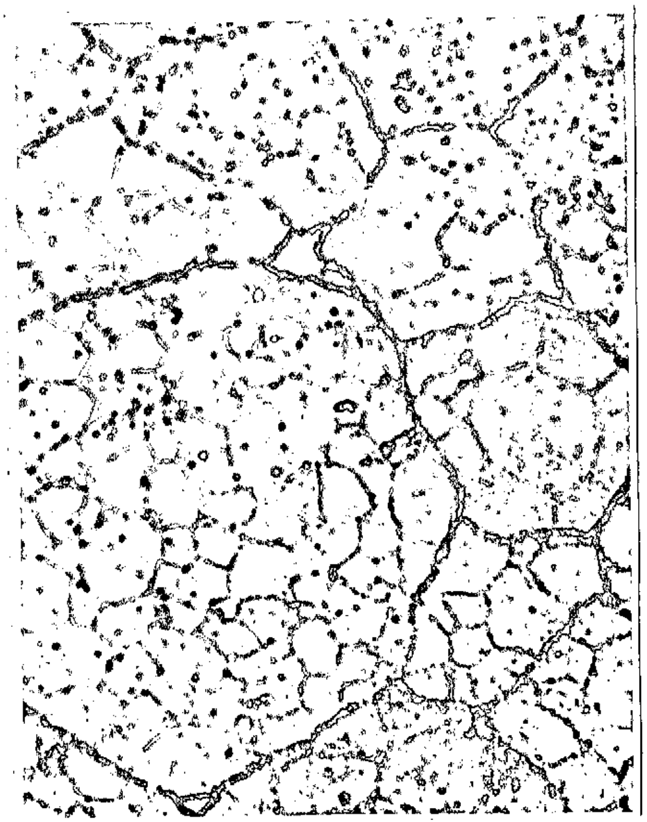

Figure 2. IN-100 nickel alloy obtained by powder metallurgy. Metallographic attack reveals the contours of the former spherules deformed during compaction, together with the much smaller grains X 1000

Another point of interest is that powder metallurgy is a method for producing alloys with dispersed second phases; the most common example is TD-nickel or TD-nickel chrome thoria dispersed in nickel or in nickel-chromium alloy. The creep resistance of these alloys is not high enough for their use in rotor blades, but there is still an appreciable strength above 1200° C. In addition, the melting point and thermal conductivity of such alloys are higher than those of other nickel-base heat-resistant alloys: they could find application in combustion chambers of future engines if the operating temperatures will have to be much higher than those of present chambers. However, sufficiently economical fabrication methods and, at least for some of the dispersed-phase alloys, effective corrosion protection will also have to be developed. The "mechanical alloying" process discovered at the International Nickel Laboratories can lead to interesting results in these two respects.

With all creep-resistant alloys, research for improved techniques of protection from hot corrosion remains an important activity, since turbine life and operating temperature must be increased simultaneously. Research on alloys with very high creep resistance has led to the sacrifice of some of their intrinsic corrosion resistance, however. New physical processes for forming protective layers have appeared, and have allowed Pratt & Whitney, for example, to produce a very effective cobalt-chromium-aluminum-yttrium coating alloy. However, thermochemical techniques such as those developed at ONERA can still be perfected: they have the advantage of providing good protection in cooling channels. For example, Figures 2 and 3 show cross sections of two protective coatings after identical long-term oxidation tests. The former was obtained by the chromaluminization process which has been used industrially for several years; the latter — by an improved process (ycralization) with a small addition of yttrium. The effect of this element, present in only a small amount, on the oxidation resistance of aluminide protective coatings is still not perfectly understood, but it is found to be very favorable (Figure 4).

2.3. Niobium (Columbium) Alloys

These alloys have high-temperature mechanical properties which are very superior to those of the nickel-base alloys, so that the operating temperatures of turbines can be increased by 100 or 200° C.

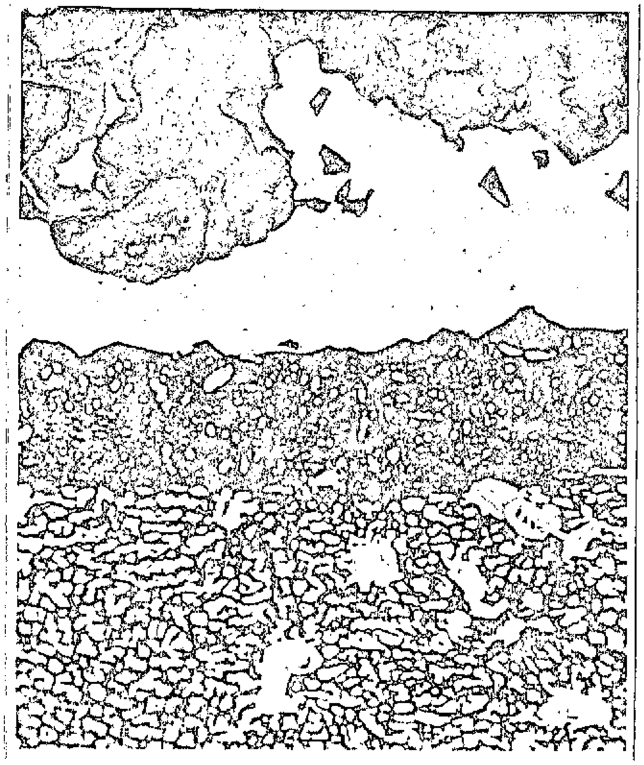

Figure 3. Section through chromaluminization coating after cyclic oxidation at 1100° C for 500 hr. X 500

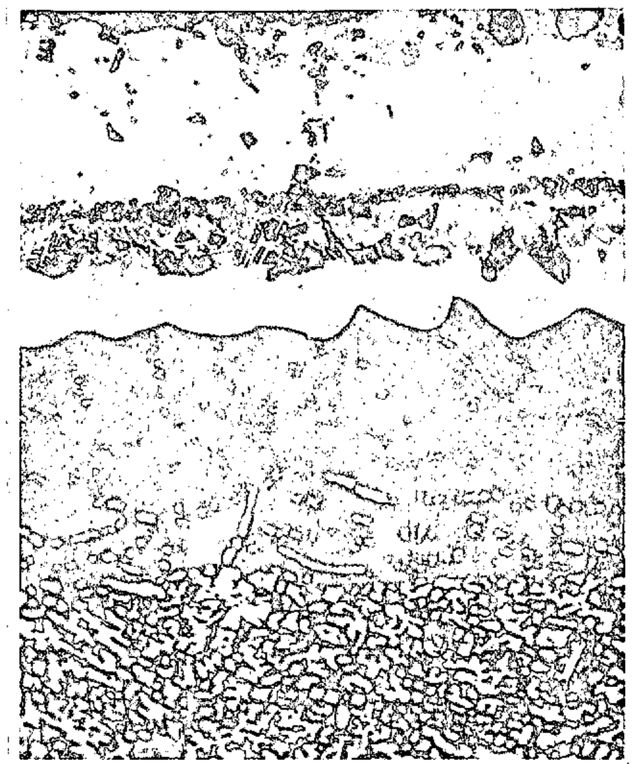

Figure 4. Section through ycralization coating after cyclic oxidation at 1100° C for 500 hr. X 500

Unfortunately, despite very many investigations, there is no known corrosion protection sufficiently effective and reliable for this type of application. It may, however, be possible in a few years to use niobium alloys in non-essential, easily-replaced components.

3. Composite Materials

Composite materials allow one to take advantage of the very high tensile strengths of fibers obtained from substances too brittle to be used in a more massive state.

The best known example is provided by glass-reinforced resins, which have long been used in the fabrication of secondary aircraft /28 structures or of solid-fuel rocket casings. The glass fibers have very high tensile strength, while their small diameters give them high flexibility. The organic resin holds them together, supports compressive loads, and distributes the load near a break in a fiber so that catastrophic failure is prevented.

Fibers with high elastic modulus — carbon fibers obtained by pyrolysis of artificial or synthetic polymers, fibers of boron vapor-deposited on a tungsten filament, organic fibers (PRD-49) produced under conditions which assure their nearly-perfect crystalline structure — have the advantage over glass that their elastic moduli are much higher (see Table below).

Fibers	Density	Tensile strength (hb)	Elastic modulus (hb)	Approximate 1973 price (F/kg)
E glass	2.5	350	7,300	5
S glass	2.5	450	8.700	10
Carbon I	1.9	210	40,000	1,000
Carbon II	1.8	280	28,000	1,000
Boron	2.7	380	38,000	2,000
PRD-49-III	1.4	250	13,000	400

In general, suitably-made unidirectional composites obey the law of mixtures quite well: the rupture strength and elastic modulus are close to the mean of the properties of each constituent, weighted by its volume fraction. The contribution from organic matrices is negligible, and the transverse mechanical properties are very poor. The volume fraction of fibers generally lies between 50 and 70%.

3.1. Composites with Organic Matrix

For applications which do not involve a high operating temperature, organic matrices are generally preferred to other types, which are denser and much more difficult to employ. Epoxy resins can be used up to about 150° C, while thermostable resins — the polyamides are presently the most highly developed — ought to be usable for long times at temperatures of at least 250° C. Even when the temperature is expected to be low, thermostable resins may be preferable for safety: their flammability is much less in case of fire.

Use of light materials is particularly desirable in the case of rotor blades in compressors and fans. The shapes of these pieces are defined chiefly by the aerodynamic conditions. Their mass is thus proportional to the density of the material. In addition, lighter blades allow an important decrease in the weight of the discs. The density and rupture strength of organic-matrix composites are very favorable, and their fatigue resistance is excellent. Their corrosion resistance is very good for boron or carbon fibers, less good for glass fibers which have a rather hygroscopic interface with the resins. The very high specific rigidity obtained with carbon or boron fibers allows blades to be designed with resonant vibrational frequencies so high they will not be excited in service, without need of bracing (fins) which is expensive to fabricate and which is harmful to performance. However, it has not been possible up to now to obtain composite blades with sufficient impact strength.

The impact strength, measured in the usual ways on smooth specimens, is of the order of 20 to 30 joules/cm^2 for glass or PRD-49 composites, even less than that of aluminum alloys, while carbon and boron fibers give impact strengths of 5 to 10 joules/cm^2. These values can be increased slightly by special arrangement of the fibers (hybrid composites), but do not attain those of aluminum alloys.

Although these results give little encouragement already, they still do not sufficiently point up the inferiority of composites reinforced by fibers which do not possess plastic elongation. With a metal, impact strength reflects the energy absorbed by the plastic deformation of a certain volume of material (although this is the practice, it is fundamentally inadequate to express it in joules/cm^2).

After plastic deformation, stopped before rupture, the ultimate strength of the damaged specimen retains a large proportion of its initial value. In the case of a composite with brittle fibers, on the contrary, the impact strength results, on the one hand, from elastic energy absorbed by deformation of the fibers before their rupture — again a case of volume energy; then, on the other hand, from the rubbing of the fibers, which tears up the matrix (Figure 5). The energy absorbed by deformation of the matrix is nearly negligible.

Only the contribution to the impact strength provided by the elastic deformation of the fibers needs be taken into consideration in estimating an upper limit to the impact strength of a rotor blade, no matter what techniques are developed to improve the overall strength, since it is quite obvious that a blade with broken fibers can no longer sustain the centrifugal forces. On the other hand, delamination will limit the rigidity of a blade which has been damaged even superficially. Now, the elastic deformation energy at the rupture of carbon, boron, or PRD-49 fibers is less than the plastic deformation energy of aluminum alloys, and the more so with respect to titanium alloys and steels. It can thus be expected, and it does indeed seem to be observed, that the results of impact tests on rotor blades will be even poorer than one would predict from the low overall impact strength of the material. /29

Figure 5. Carbon/resin composite broken in flexure by impact

The pessimism which I have just expressed does not, however, imply that use of composites should be judged impossible, or without advantage in turbojets. For components not exposed to impact — such as internal housings — or even for components which may be exposed only to impacts at relative velocities less than those of the rotor blades — air intakes, intake stator blades — composites with organic matrices can, it may be hoped, lead to very considerable weight reductions — 20 to 50% — over identical metallic components, even taking into consideration the reinforcements required by connections.

In addition, composites can be used for the circumferential reinforcement of compressor discs, and allow lightening by about 20%.

The relative positions of boron fibers, carbon fibers, and organic fibers of the PRD-49 type will depend to a large extent on their respective prices: produced in large quantities, the latter two seem to be clearly less expensive. At the moment, PRD-49 composites have mediocre compression strength, which can prevent certain applications.

3.2. Composites with Metallic Matrix

Boron fibers retain high mechanical strength up to 1000° C; at very much higher temperatures the strength of carbon fibers should remain practically the same as at room temperature. People have tried to use them to reinforce metallic alloys. Aluminum-alloy composites reinforced by boron fibers are obtained by diffusion-bonding of clad fibers in a plasma torch, or of fibers simply interposed between metal foils.

Use of boron fibers pre-clad with a diffusion barrier, for example, silicon carbide (Borsic, by Pratt & Whitney), provides good chemical compatibility. At room temperature, these composites have mechanical properties similar to those of boron-resin composites, but their density is higher — about 2.7. They can be used up to

500° C, at which point their tensile strength is still about half that at 25° C. However, the shear strength of the matrix is very low at this temperature.

Investigation of other metallic composites is less advanced. Carbon aluminum composites, for which ONERA has developed a simple method of fabrication by liquid-metal impregnation, have room-temperature mechanical properties similar to those of the boron-aluminum composites: their ultimate strength, of the order of 100 hb for a unidirectional composite, is constant up to at least 350° C. The carbon-aluminum composites must be prepared in such a way that the carbon fibers do not appear at the surface of the material; if they do, the corrosion resistance is very poor.

In an entirely different area, one can point out the nickel alloys reinforced by tungsten fibers which have been studied extensively by NASA. They have a very high creep resistance out toward 1100 or 1200° C. They have good high temperature impact strengths because the tungsten fibers are ductile. Unfortunately, they seem very sensitive to thermal cycling, which cracks the matrix, probably because of the large difference between the coefficient of expansion of the fibers and that of the matrix.

4. Directionally-Solidified Eutectics

These materials, to which ONERA has devoted large efforts in the Research and Test Methods Directorate, are not all eutectics in the strict sense. They are also called "*in situ* composites" or "natural composites", in contrast to the artificial composites which have just been discussed. They have a microscopic two-phase structure, fibrous or lamellar, which they acquire spontaneously during unidirectional solidification.

It has been known for a very long time that many alloys of two metals are entirely miscible in the liquid, yet for a certain composition called the eutectic composition, have the following peculiarities:

— like pure metals, but unlike most alloys, these eutectic alloys have a single solidification temperature, which is less than that for alloys with nearby compositions;

— once they have solidified, they are constituted of two phases which are solid solutions, rich in the respective component. In general, these phases are finely divided and can be distinguished only by use of a microscope; they are single-crystalline, and often possess the very high mechanical properties of whiskers.

There are also eutectics between different compounds of two elements, as well as eutectics between a greater number of simple or compound components.

There is thus available an elegant method for preparing very diverse composites which can possess valuable physical or mechanical properties. Many investigators have attempted to produce high-temperature creep-resistant materials by this means; it does seem reasonable to hope that composites containing whiskers in a matrix with which they are chemically compatible could possess very high mechanical properties.

Since the eutectics solidify at a single temperature under near-equilibrium conditions produced in the directional-solidification apparatus, the solidification front is an isothermal surface, in general, the fibers or lamellae grow perpendicular to the solidification front. Thus, a planar isothermal surface is desired, which should be advanced parallel to itself through the material.

It is also necessary that the ratio of the thermal gradient in the liquid to the solidification rate be greater than a certain critical value which is a function of the alloy composition. This value is usually between 10 and 100° C · hr/cm^2. /30

The diameter of the fibers or the thickness of the lamellae formed during solidification of a given alloy are approximately inversely proportional to the square root of the solidification rate. To obtain a regular structure thus requires a constant solidification rate.

4.1. Fabrication

Most devices used for directional solidification of eutectic alloys can be represented schematically by Figure 6: a moving crucible with its axis vertical moves downward at constant velocity between a fixed heater and a cooler which may be either fixed or attached to the crucible.

The heater can be a resistance furnace or a high-frequency induction heater with a susceptor. In these two cases, the heat reaches the alloy by radiation from the heating element to the crucible, then by conduction through the crucible. Direct induction heating of the alloy can also be used: the heat is then supplied directly to the surface of the alloy.

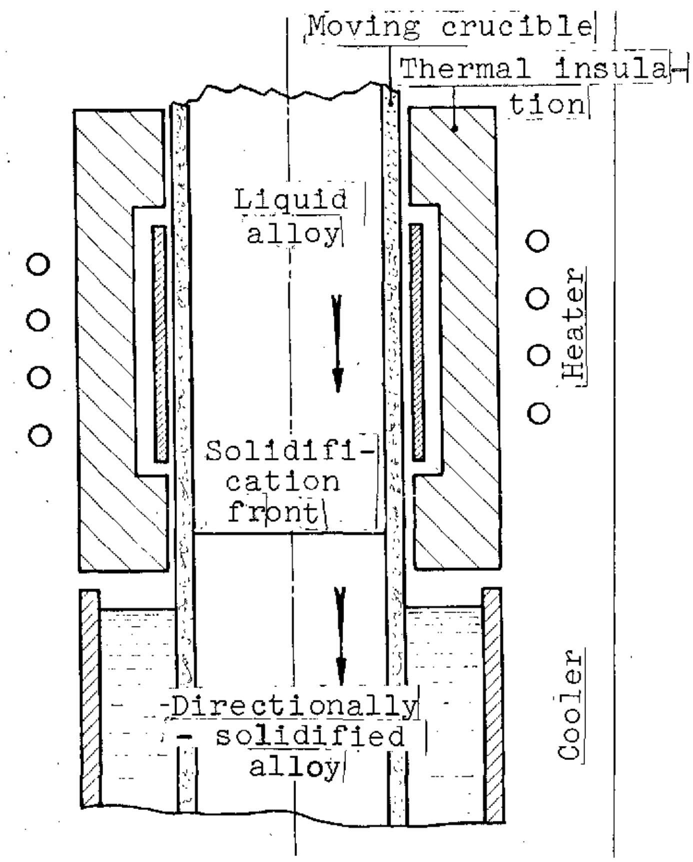

Figure 6.

The cooler is either a bath of liquid maintained at constant temperature, or a device which cools by means of streams of water or jets of gas. The distance between the cooler and the heater is fixed. If the heater power is suitably regulated, the solidification rate is constant and equal to the crucible displacement rate, and the thermal gradient remains constant.

The heating and cooling must be carefully controlled and the crucible motion must have no irregularities. A progressive variation in the solidification rate results in a modification of the transverse dimensions of the lamellae or fibers, which must thus divide or converge, or at least some of them may appear or disappear. In any case, the mechanical properties of the composite will be degraded. An abrupt variation of the solidification rate forms a band where the eutectic, having completely lost its fibrous or lamellar structure, possesses only the properties of a non-oriented eutectic; this is generally valueless.

4.2. Structure of Directionally-Solidified Eutectics

The microstructures of two-phase eutectic alloys belong, in general, to two main types:

— lamellar microstructure, where each phase appears as alternating parallel lamellae or ribbons inside a single grain. The lamellae can be continuous in the solidification direction, but there are many irregularities in the perpendicular directions. This fact, together with the frequent presence of several grains in the same section which have only one crystallographic direction in common, parallel to the growth direction, requires that these materials be considered unidirectional composites;

— fibrous microstructure: depending on the alloy, the fiber cross section is polygonal (Figure 7) or curvilinear (Figure 8). This microstructure occurs in eutectics where one of /30 the phases occupies less than 30% of the total volume. The shape of the fiber cross section often depends on the growth rate. It can be modified by slight variations in chemical composition. Certain alloys, lamellar when they are solidified slowly, take on a fibrous structure at a higher solidification rate.

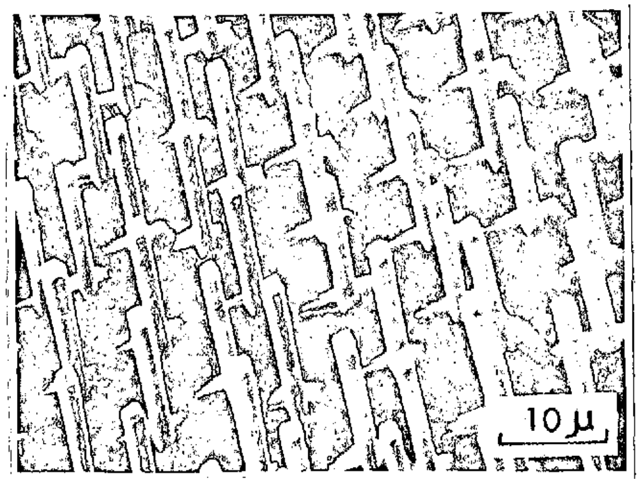

Figure 7. Ni-Cr/TaC alloy. Fibers in relief from chemical attack on the matrix

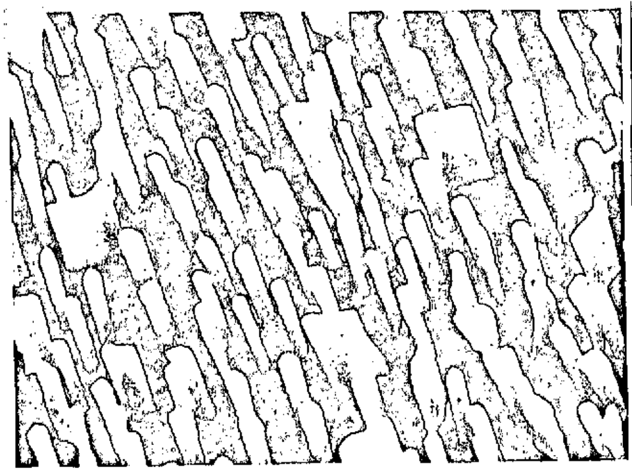

Figure 8. Co-Cr-Ni/TaC alloy. Fibers in relief from chemical attack on the matrix

Alloys which could be suitable for fabrication of turbine blades must possess the following:

— melting temperatures well above 1200° C;

— densities less than or only a little greater than that of present superalloys, and in any case less than 10;

— acceptable resistance to accidental impacts;

— good intrinsic oxidation and hot corrosion resistance; a protective coating will probably be necessary, but the base alloy must not undergo catastrophic corrosion if the coating is damaged;

— higher creep strengths than present superalloys under loads of 10 to 30 hectobars;

— resistance to mechanical and thermal fatigue at least equal to that of present alloys.

On the basis of present knowledge, it appears that only iron-, nickel-, or cobalt-base alloys with a rather high chromium or aluminum content can be sufficiently corrosion resistant.

Among the alloys with eutectic structures which have been studied so far, three groups seem to satisfy the above conditions in whole or in large part:

— those discovered at ONERA, derived from pseudo-binary eutectics of cobalt, nickel, or iron, and high-melting monocarbides. The cobalt/tantalum carbide eutectic shows good creep resistance and satisfactory ductility, but it is very oxidizable. With this as a starting place, it has been possible to obtain eutectic materials reinforced by carbides of tantalum, niobium, or other metals, in which the matrix is a cobalt or nickel alloy containing a large amount of chromium. The material as a whole thus possesses oxidation and hot-corrosion resistance comparable to that of present superalloys. In addition, it has been possible to obtain a very large family of fibrous composites in which the matrix is a face-centered-cubic alloy of iron, nickel, cobalt, and chromium, and the fibers are simple or mixed monocarbides such as TiC, HfC, NbC, TaC. Aluminum is also included in the matrix of these alloys to improve hot-corrosion resistance; so is titanium, so that in nickel-rich matrixes there is hardening by precipitation of $Ni_3(Ti, Al)$. Matrix hardening by incorporation of molybdenum, tungsten, or an excess of the metal forming the monocarbide is also possible;

— the pseudo-binary eutectic $(Co, Cr)/(Cr, Co)_7 C_3$, discovered by United Aircraft, with a structure containing irregularly-shaped carbide fibers. It can be modified by addition of aluminum. The great ease with which this alloy can be directionally solidified allows use of very high solidification rates; this technique improves the creep resistance of the alloy, which is poorer than that of monocarbide eutectics.

— the pseudo-binary lamellar eutectic Ni_3Al/Ni_3Nb, also discovered at United Aircraft. It contains two intermetallic phases, the first of which is ductile. It is relatively easy to directionally solidify, and its creep resistance is exceptionally high. The overall ductility is low at room temperature, but becomes rather high at high temperatures. Its intrinsic oxidation resistance is poor. The composition of this type of alloy can be modified, but seemingly less than that of the alloys containing monocarbides. A ternary $Ni/Ni_3Al/Ni_3Nb$ alloy has been obtained recently. Its properties are quite similar to those of the pseudo-binary eutectic.

4.3. Properties of Some Directionally-Solidified Eutectics

The wide range of test methods makes it hard to compare the impact strengths of the different sorts of alloys. In all cases, there is a large effect of the anisotropy of these directionally-solidified materials: the strength is greatest when the specimen length is parallel to the solidification direction, least when the test conditions are such that the crack propagates in that direction.

The Co-Cr-Ni/TaC alloys have high strength when the fibers are parallel to the specimen axis. Cylindrical smooth Charpy specimens will bend through 60° at room temperature without fracturing, and through more than 100° at 1000° C, although the elongation at rupture measured in tensile tests at this temperature is rather low (Figure 9). The energy absorbed is more than 210 joules/cm^2. This behavior results from the high ductility of the matrix and the low volume fraction of fibers (10%). Even when the fibers are fractured, the alloy retains appreciable strength.

Published results for Co-Cr/(Cr, Co)$_7$ C$_3$ eutectics and Ni_3Al/Ni_3Nb seem to show much more brittle behavior.

The oxidation resistance of certain alloys in the family Fe-Co-Ni-Cr-Al/monocarbide, which is of particular interest because of the large number of chemical compositions available, is greater than that of classic superalloys. All the monocarbides are very oxidizable in the massive state, but since the fiber diameter, of the order of a micron, is much less than the thickness of the oxide layer which forms on the alloy after a few hours at high temperature, these materials /32 behave as if they were homogeneous from the standpoint of high-temperature oxidation. The oxidation curve of chromium-rich alloys is parabolic, and those reinforced by tantalum carbide are less rapidly oxidized than those containing niobium carbide. The oxide formed on these alloys does not scale on cooling, and the weight gain recorded during a test consisting of several 5-hour heating cycles is little different from that produced by continuous heating. Application of chromaluminization by the ONERA process has produced results as satisfactory as those observed on classic superalloys during cyclic corrosion tests with combustion gases.

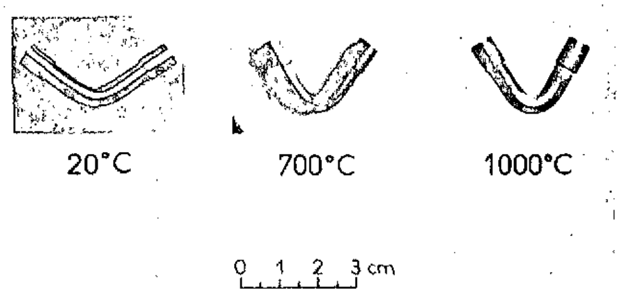

Figure 9. COTAC-3 solidification composite bent by impact

Figure 10 compares the creep resistance of two types of eutectics to that of classic alloys: Nimonic 80A, used for rotor blades in turbojets built around 1950; cast In-100, used in the Concorde engines, and which seems to have about the highest performance to be expected from classic nickel alloys; directionally-solidified DS 200 nickel; and TD-Ni, thoria-dispersed nickel. The two dashed curves show the temperatures and representative specific constraints for two current types of rotor blades. The value of the directionally solidified eutectics appears clearly. In addition, their fatigue resistance is higher than that of the usual alloys.

The principal of eutectic solidification, taking place under conditions very near local thermodynamic equilibrium, implies that the solid phases present are stable in composition and proportion quite near the melting point. Composites obtained by solidification thus do not display at high temperature those phenomena of chemical incompatibility encountered in composites with metallic matrixes produced by other techniques. However, nothing says a priori that the microstructure of a directionally solidified eutectic is stable; in some cases, long-time aging leads to disappearance of some fibers and coarsening of others, or to disruption of the fibers into spheroidal sections. In other cases, particularly when the interfaces are well-defined crystallographic planes, the microstructures are remarkably stable. This is the case for (Co-Cr-Ni)/TaC and Ni_3Al/Ni_3Nb.

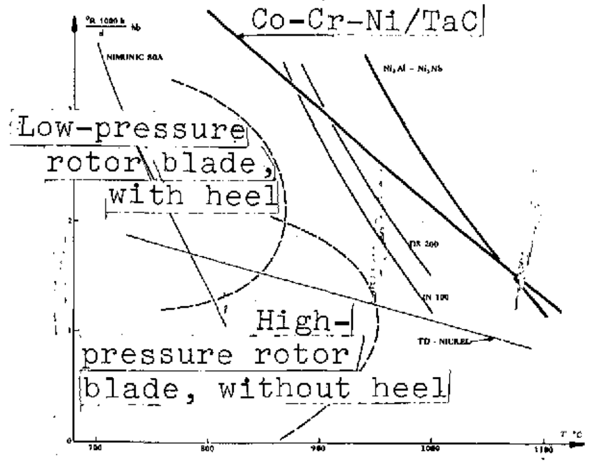

Figure 10.

Large internal stresses appear within the alloys when their constituents have widely different thermal expansion coefficients. These internal stresses, which vary cyclically in jet engine blades, must be taken into consideration in predicting blade life.

While the simplest properties of the eutectic alloys are starting to be understood, the study of the thermal stability will be playing a more important role in the characterization of alloys which are already known, and in research for improved alloys.

It is particularly on the results of these studies and also, of course, on the development of reasonably economical methods of fabrication that the future use of directionally-solidified eutectics in jet engines will depend. At the present time, together with the development of cooling techniques, they appear to offer the best chance of increasing the gas temperature at the turbine intake.

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15. Supplementary Notes

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16. Abstract

Tendencies in the evolution of alloys used at present in turbomachine construction are first recalled. The techniques of powder metallurgy and of unidirectional solidification should, in particular, permit a better use of nickel alloys. Application perspectives for composite materials are examined. While the impact resistance of these materials is insufficient in the case of compressor rotor blades, their other mechanical characteristics should permit an important weight alleviation of other parts, less exposed to shocks. Lastly, the oriented eutectics, alloys of particular composition which take up a composite structure by unidirectional solidification, present a set of properties which let it be expected that some of them will be used for making turbine blades or vanes, capable of withstanding significantly higher temperatures than those tolerated by conventional alloys.

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